A STUDY ON SEASONAL VARIATION OF LEVELING DATA IN OMAEZAKI REGION

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  - Leveling survey in Omaezaki region
- Seasonal variation
  - Its feature
- Effect of atmospheric refraction
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1. Introduction

Leveling Survey in Omaezaki Region

- Why it is important ?

  It is carried out to monitor the vertical movement near the seismogenic area of coming Tokai Earthquake.

The reason of seasonal variation has been *unknown*

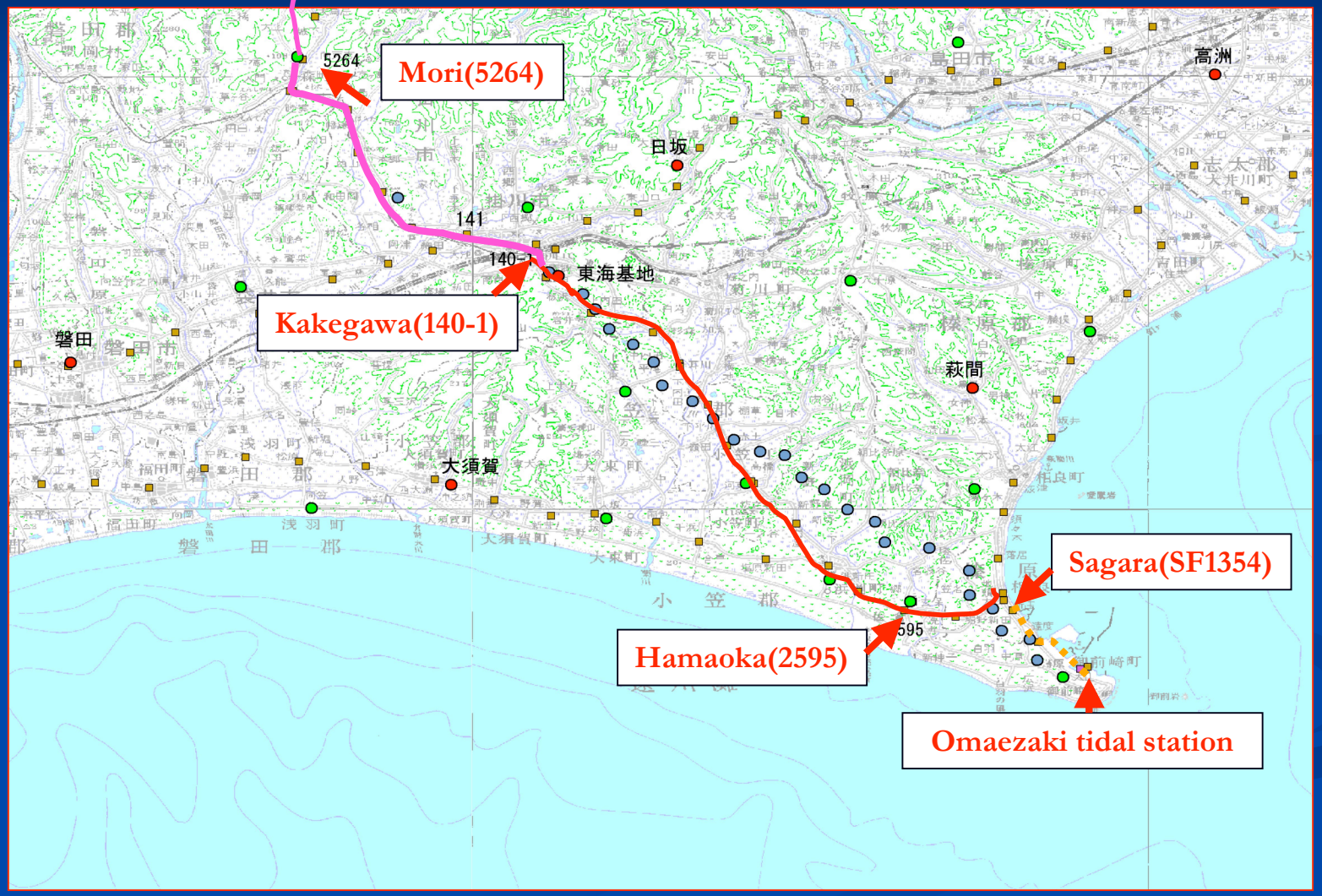
  Subsidence of Omaezaki referred to Kakegawa, about 5mm/year for 25km leveling route, caused by the subduction of Philippine Sea Plate

- And…

  Seasonal variation was found by the frequent (every 3 months) survey starting from 1981.

Location of Omaezaki

Leveling Route in Omaezaki Region



2. Seasonal variation

- Leveling survey In Omaezaki region is repeated four times per year

  January, April-May, July, October

- Sinking rate is not constant → seasonal variation

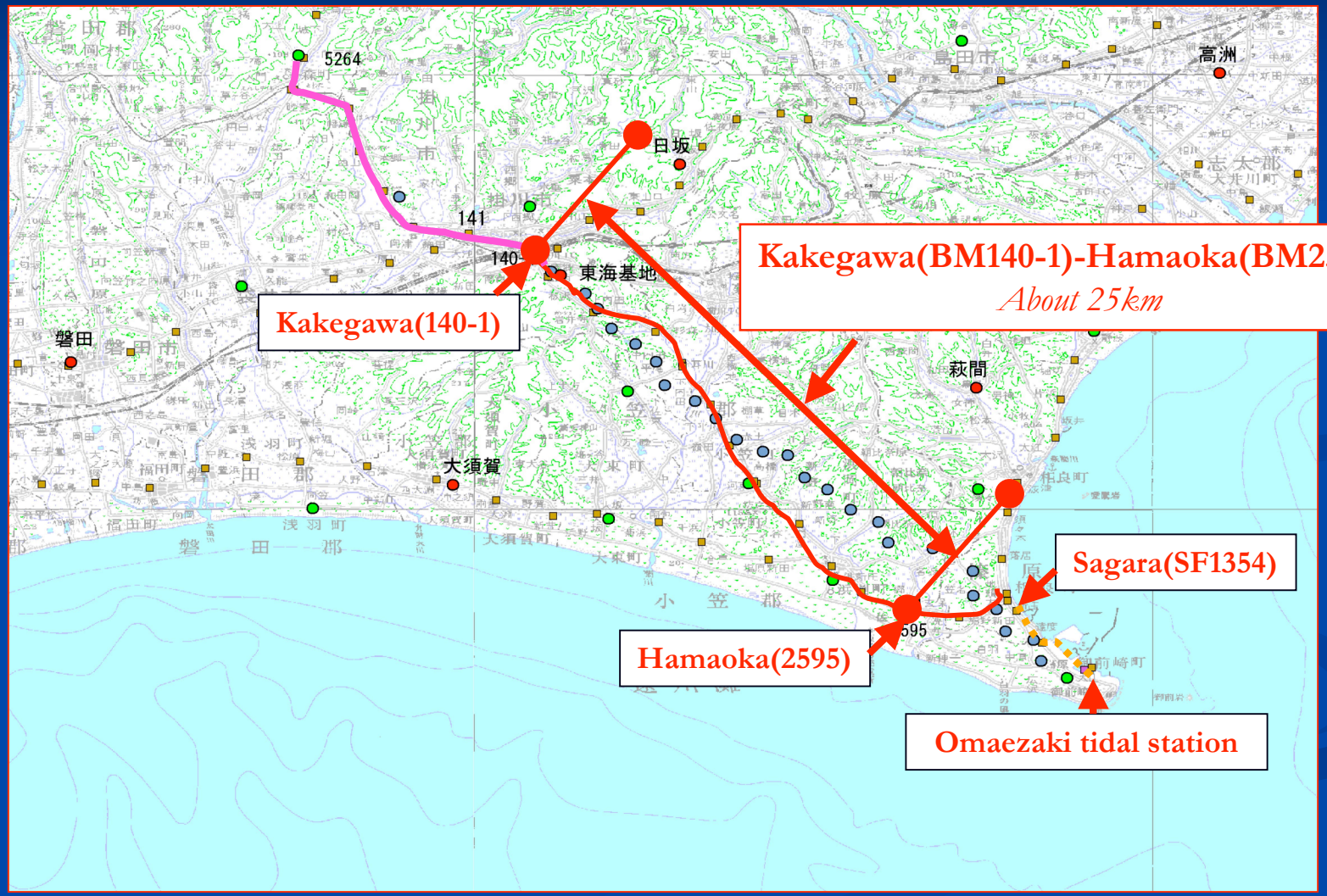
  Sinks more in winter, less in summer

- Seasonal variation can be seen not only in the peninsula but also inland region

  (Mori to Kakegawa)

- Seasonal variation can be modeled by sine function with one year cycle

Seasonal variation in peninsula

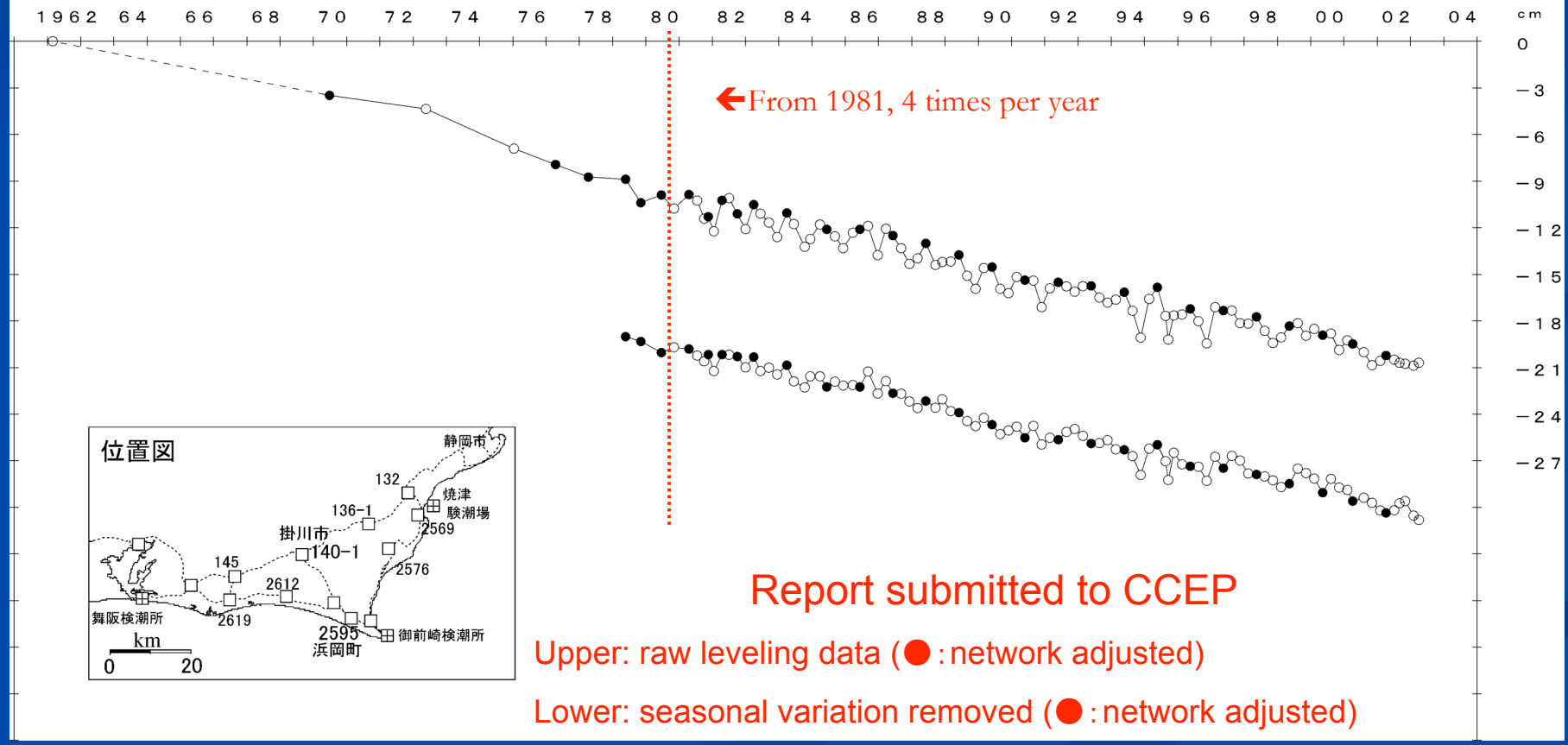


Trend of vertical movement

Hamaoka(2595) to Kakegawa(140-1)

●：網平均計算値による。

回帰式　Ｙ＝－４．６４＊Ｘ－２．０５＊ｓｉｎ（２＊π＊Ｘ）－６．３２＊ｃｏｓ（２＊π＊Ｘ）



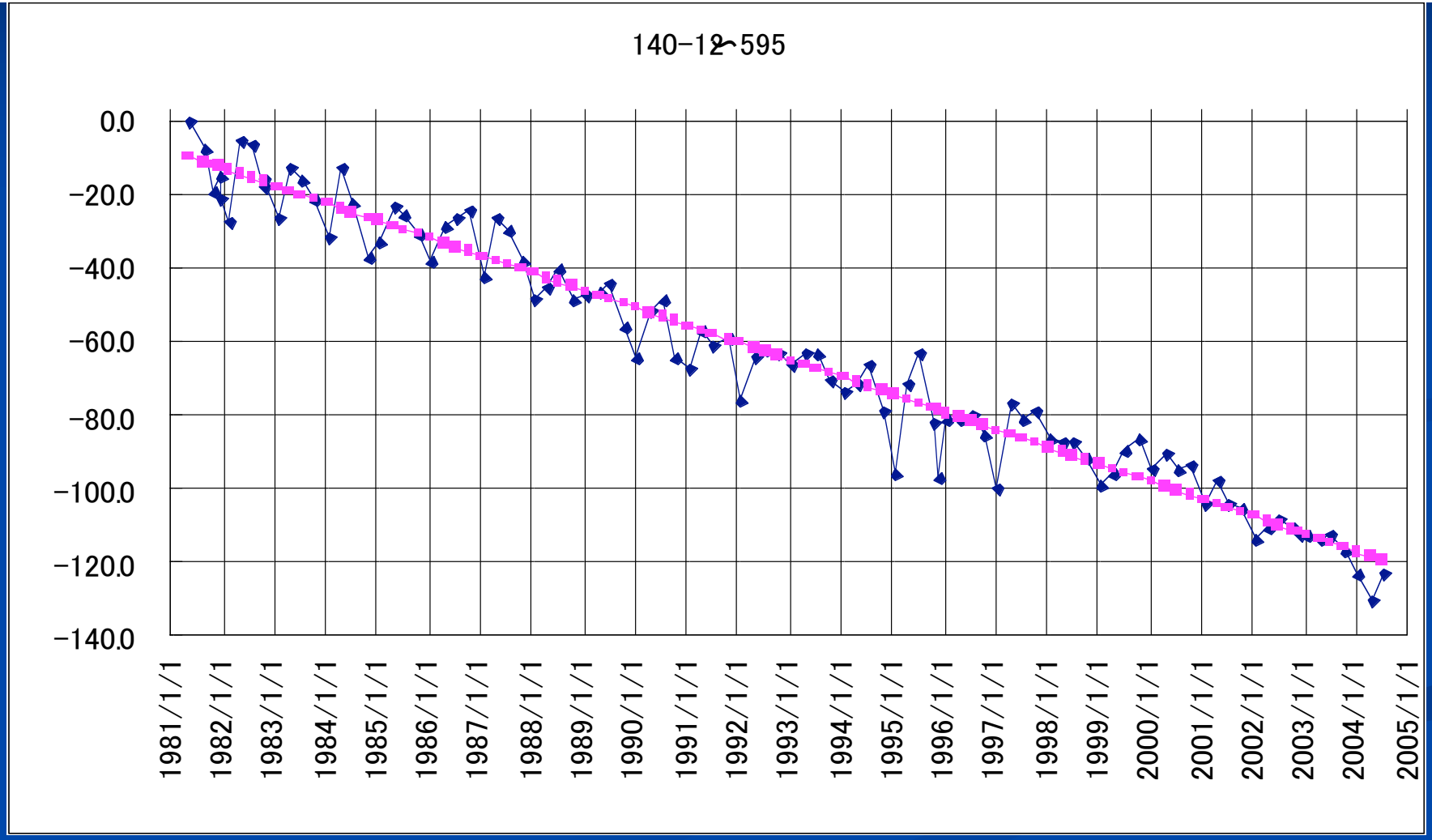
Report submitted to CCEP

Upper: raw leveling data (●: network adjusted)

Lower: seasonal variation removed (●: network adjusted)

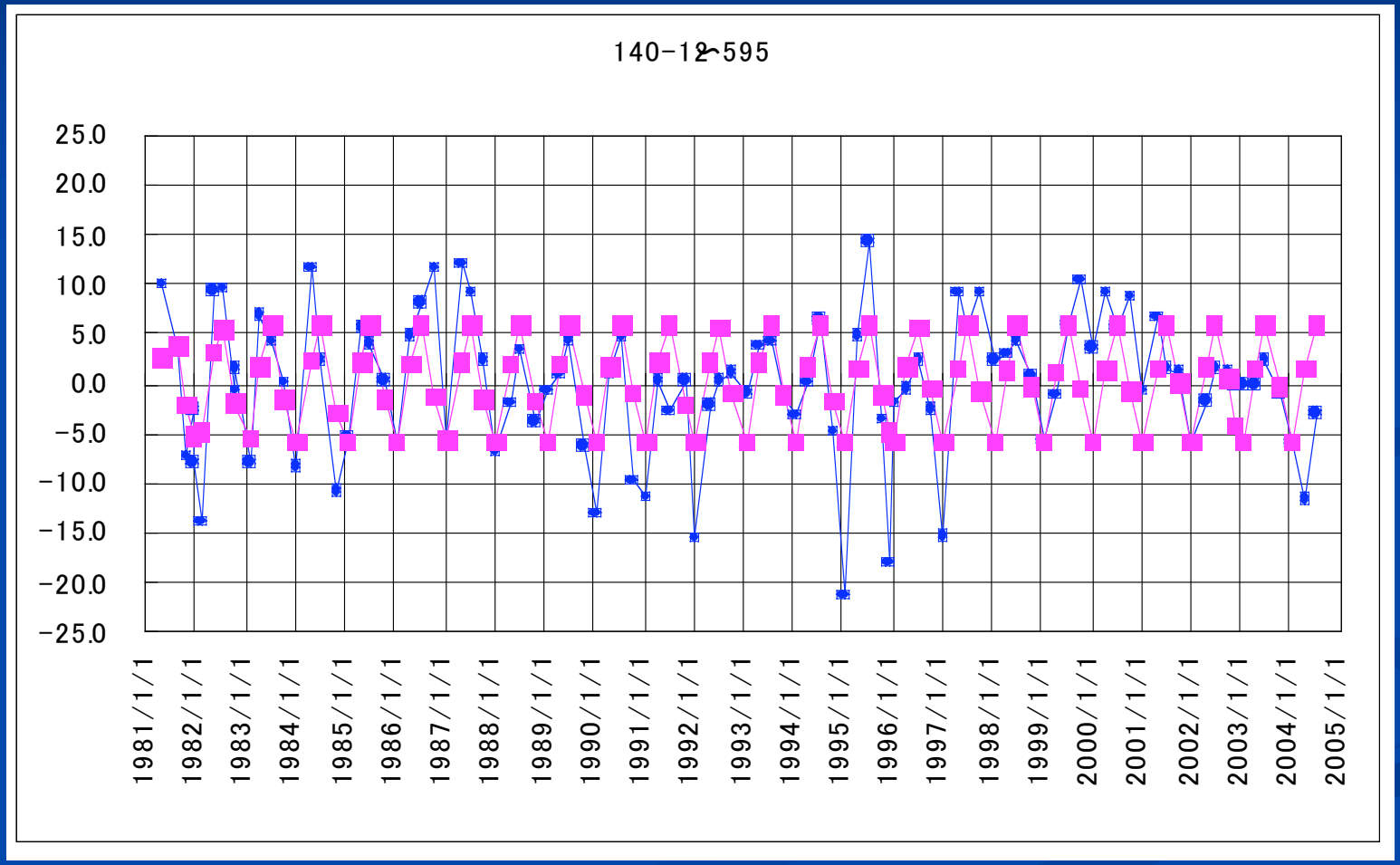
Trend of vertical movement

Hamaoka(2595) to Kakegawa(140-1)



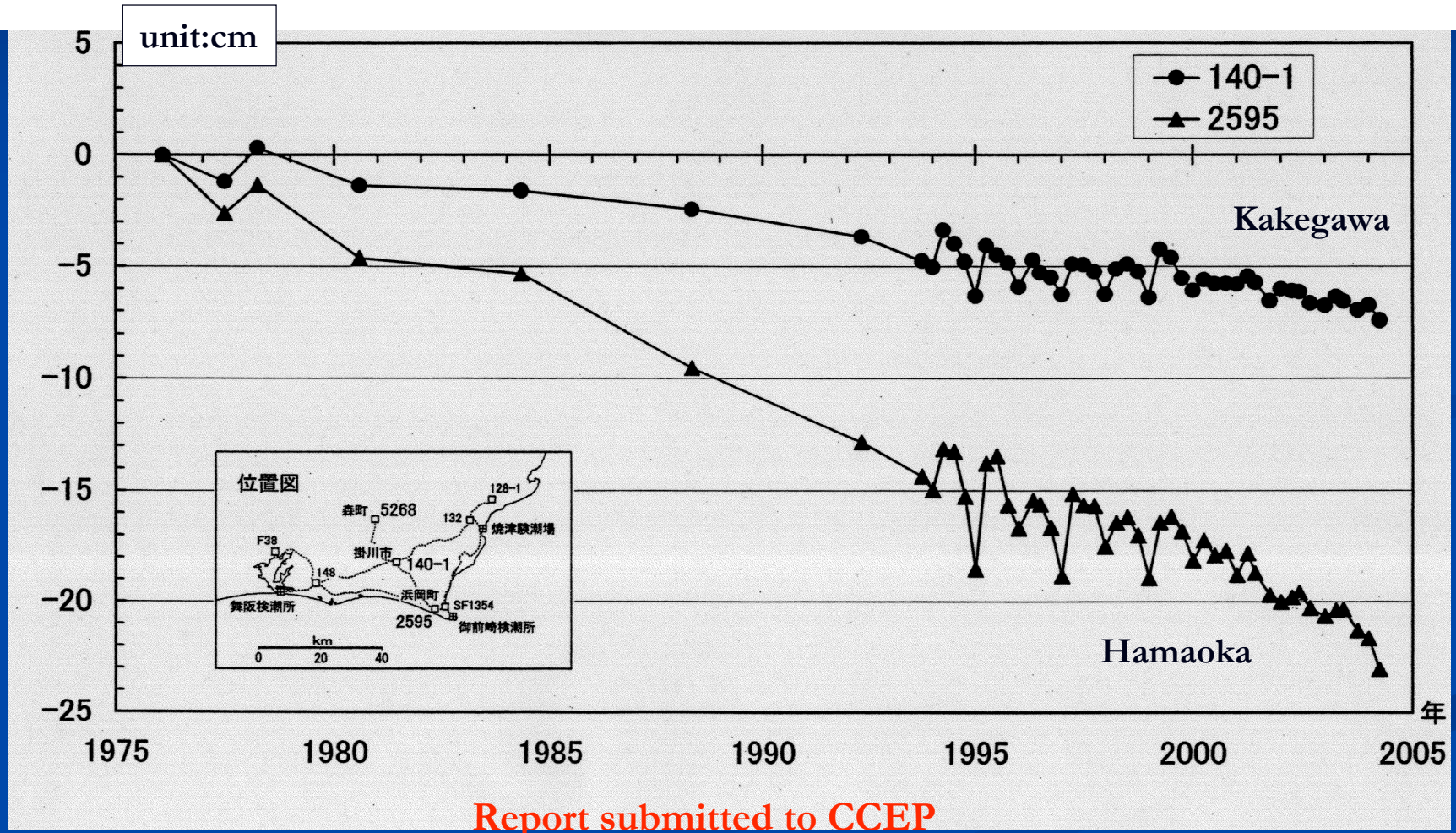
Seasonal variation

- residual removing linear trend -



North part of the Leveling Route

Vertical movement of Hamaoka(2595) and Kakegawa(140-1) referred to Mori(5268)



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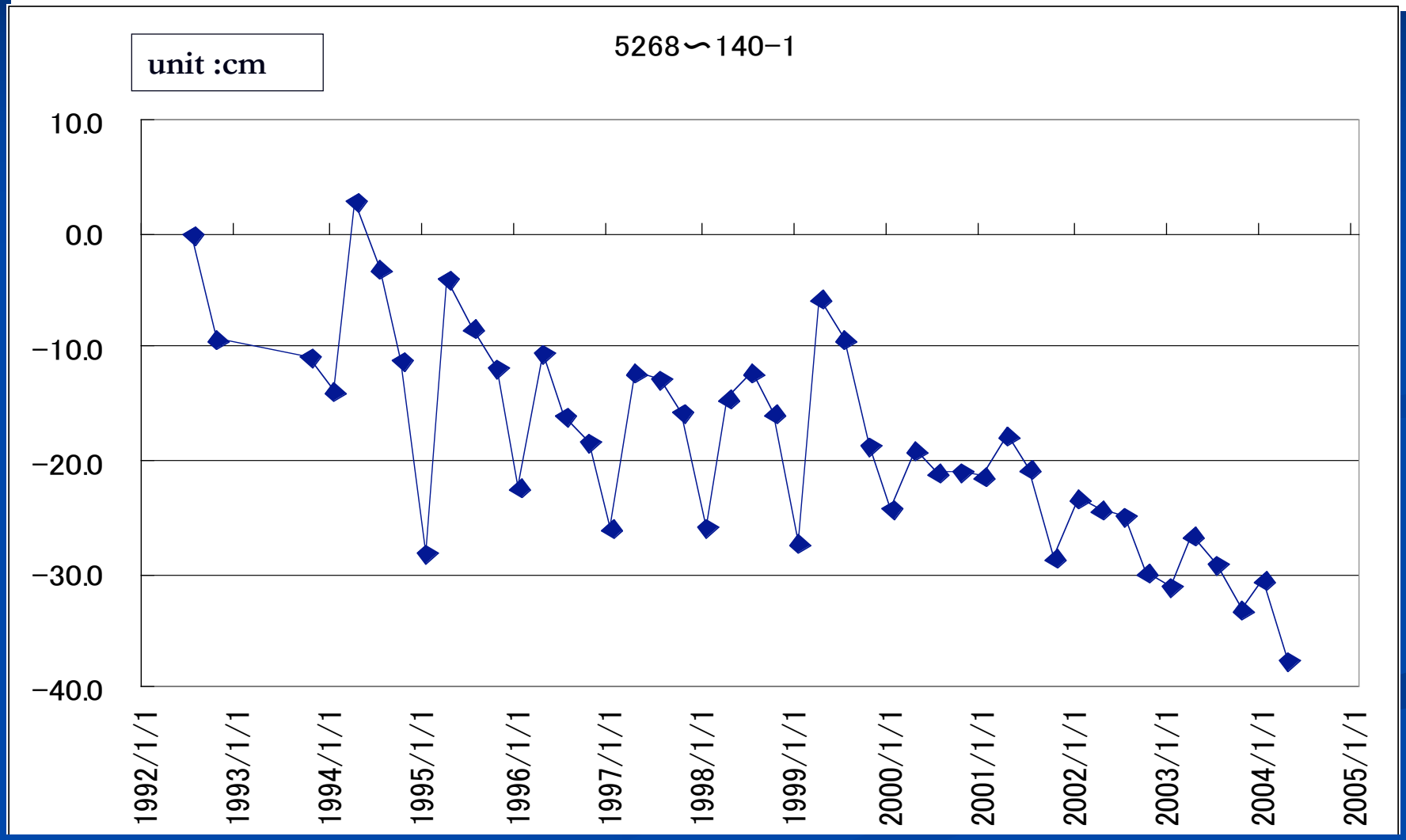
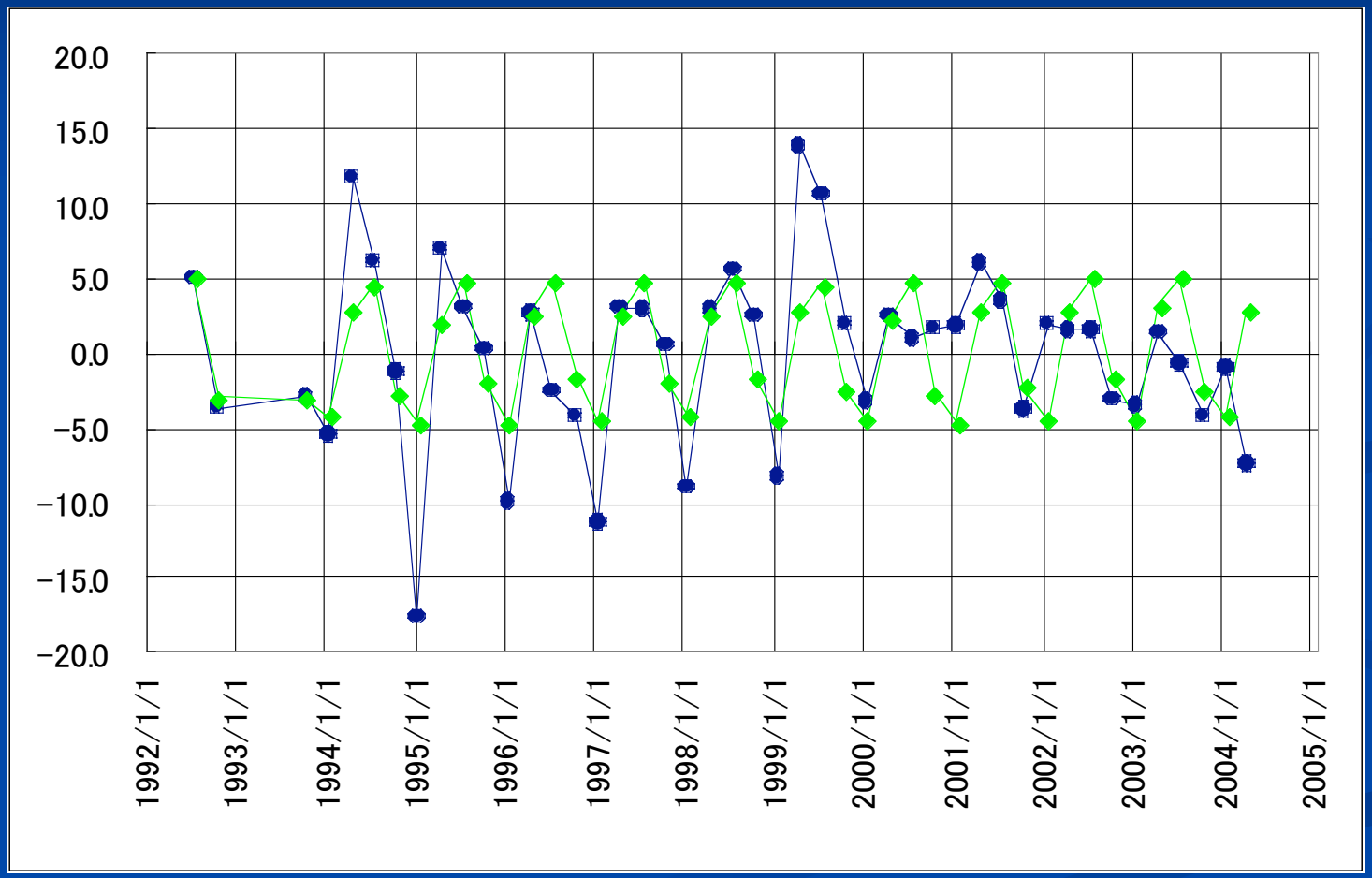
Trend of vertical movement of Kakegawa



Seasonal variation

- residual removing linear trend -

Kakegawa(140-1) referred to Mori(5268)



Notable features in seasonal variation

- Amplitude of seasonal variation is 10mm (peak to peak) in the route between Hamaoka and Omaezaki, and Mori and Kakegawa
- Vertical movement of Hamaoka is **"up" in summer** and **"down" in winter** (referred to Kakegawa), and Kakegawa is **"up" in summer** and **"down" in winter** (referred to Mori), too
- Amplitude of variation is smaller recently
- Same pattern of seasonal variation is found in the short leveling route, where Shizuoka prefecture is carrying out leveling survey every two weeks

Studies on the origin of seasonal variation

- "True" vertical movement is suggested
  - Weight of sea water (Tajima et al,1984)
  - Underground water level (GSJ,1987)

- "not-True" movement caused by leveling procedure is suggested
  - Tide effect (Hosono,Inouchi,1987)
  - Deflection of plumbline (Tajima,Imakiire,1998)
  - Atmospheric refraction (Sagiya,Nemoto,2000)

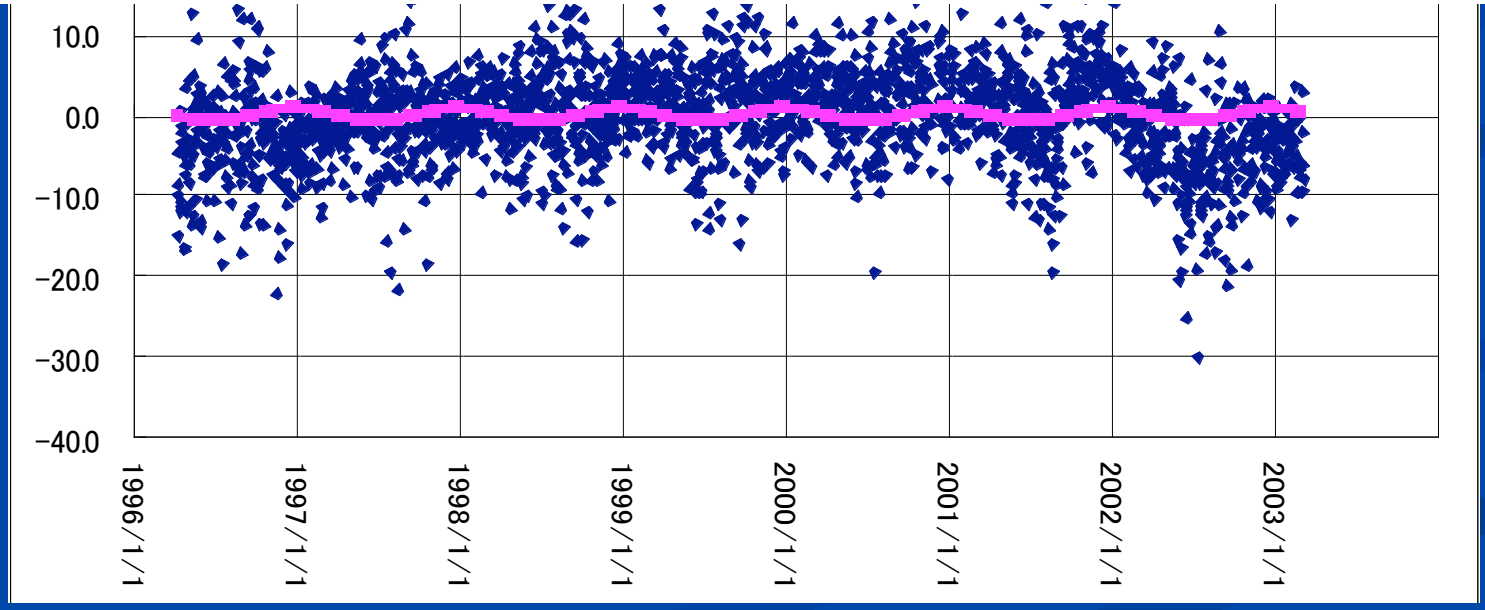
The facts necessary to explain

- The amplitude of seasonal variation is too large to explain by all mechanism which have been proposed
- The seasonal variation detected by GPS survey is much smaller (less than 2mm)
- Seasonal variation is detected even though the height difference between 140-1 and 2595 is very small (less than 1m for 25km leveling route)

Vertical movement observed by GPS

KAKEGAWA--OMAEZAKI

Atmospheric refraction is the main cause of the seasonal variation ?



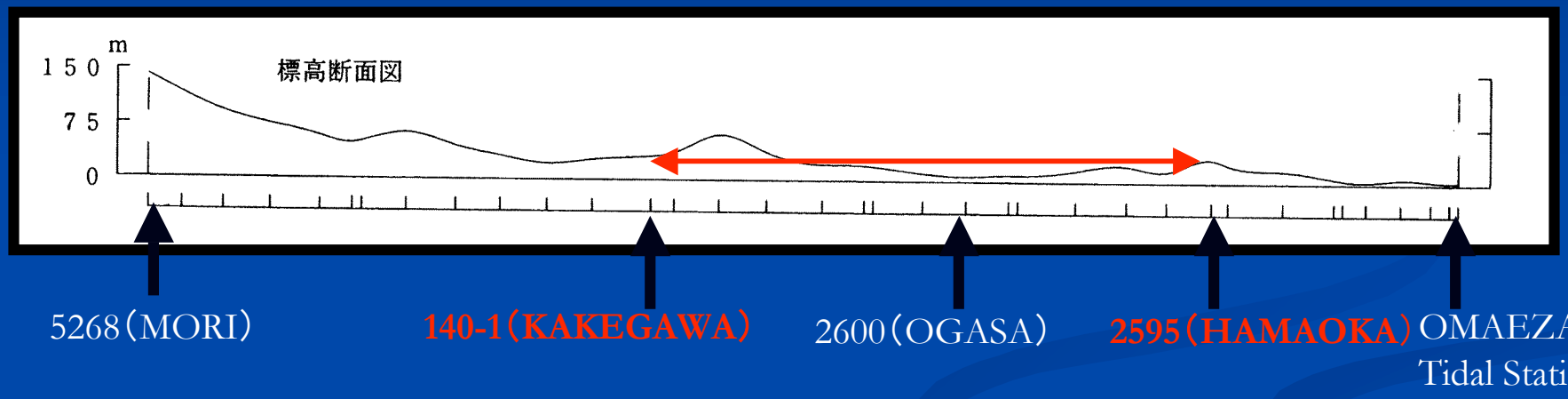
Amplitude of seasonal variation is small

3. Effect of atmospheric refraction

- "Vertical difference of the temperature of atmosphere causes the refraction of line of the sight for leveling observation"

- IF refraction is the main reason of seasonal variation …
  - Amplitude of seasonal variation should have positive correlation with absolute value of height difference
  - Phase of seasonal variation should be reverse between the descending section and ascending section

Topography of leveling route from Mori to OMAEZAKI



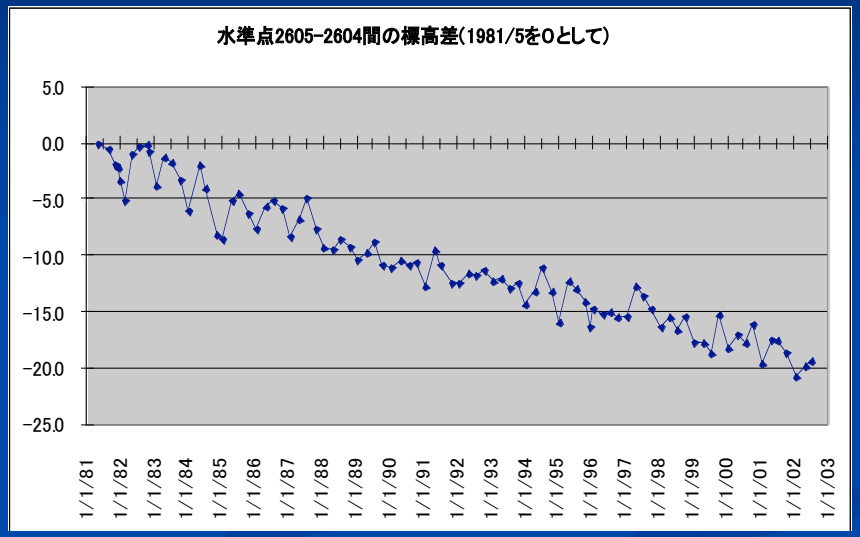
- The height difference of 140-1 and 2595 is less than one meter.
- The height difference between the highest point and lowest point in the route from Kakegawa to Omaezaki is about 50m.
- Height difference in each section(2km) is from 2m to 25m.

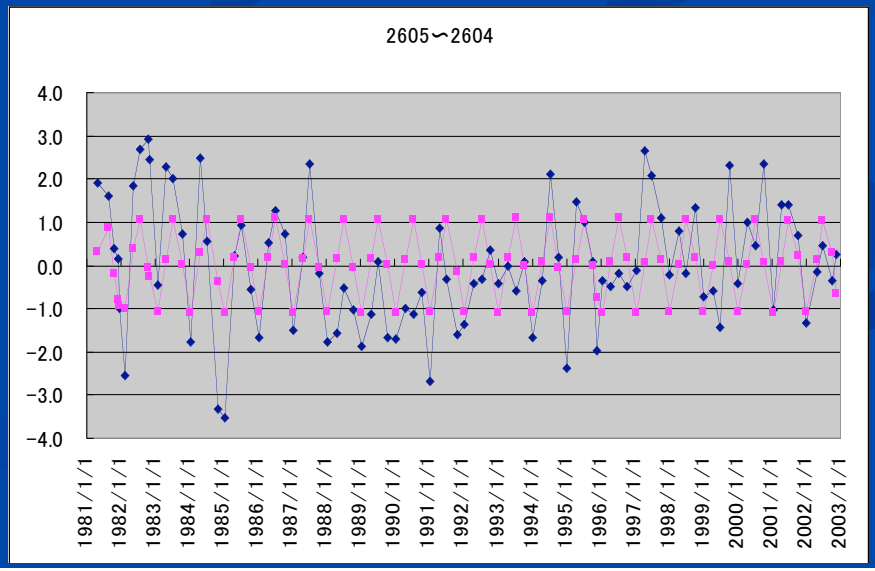
Seasonal variation in each section

- 13 sections from Kakegawa to Sagara are selected, where leveling survey has been carried out 4 times per year since early 1980s
- Time series of height difference is fitted to linear model and one year cycle sine function (annual variation)
- Akaike Information Criterion (AIC) is calculated for linear model and linear + annual variation model to determine which is preferable
  - The sections where seasonal variation is clearly seen(9/13)
  - The sections where seasonal variation isn't found(4/13)

A section where annual variation is seen

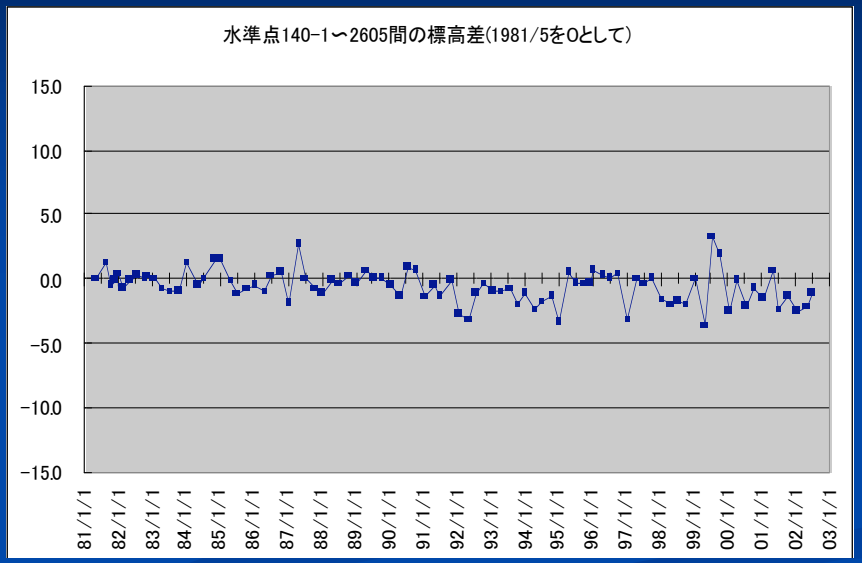
- The graph is the time series of height difference between BM2605 to BM 2604
- The amplitude of annual variation estimated is 2mm (peak to peak)

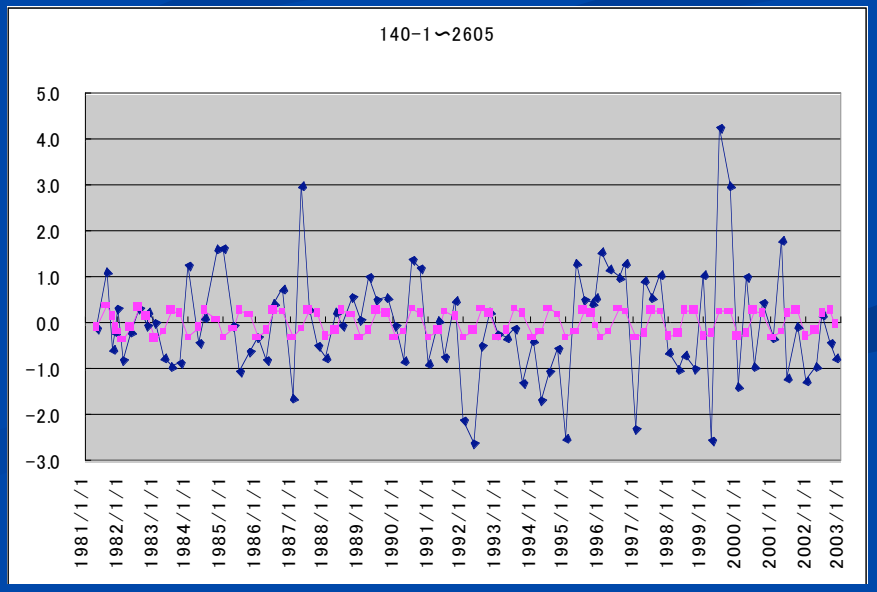




A section where no annual variation is seen

- The graph is the time series of height difference between BM140-1 to BM 2605
- The annual variation is not clearly seen





Testing models by AIC

- AIC(M)=-2 * MLL(M) + 2 *k
  - *MLL: Maximum Logarithm Likelihood*
  - *k: number of parameters in model*

↓

- Determine preferable model by AIC. (the model which gives smaller number is preferable)
  - Linear model : k=2 ($\Delta h = \mathbf{a}t+\mathbf{b}$)
  - Linear + annual variation model : k=4

Comparison of models

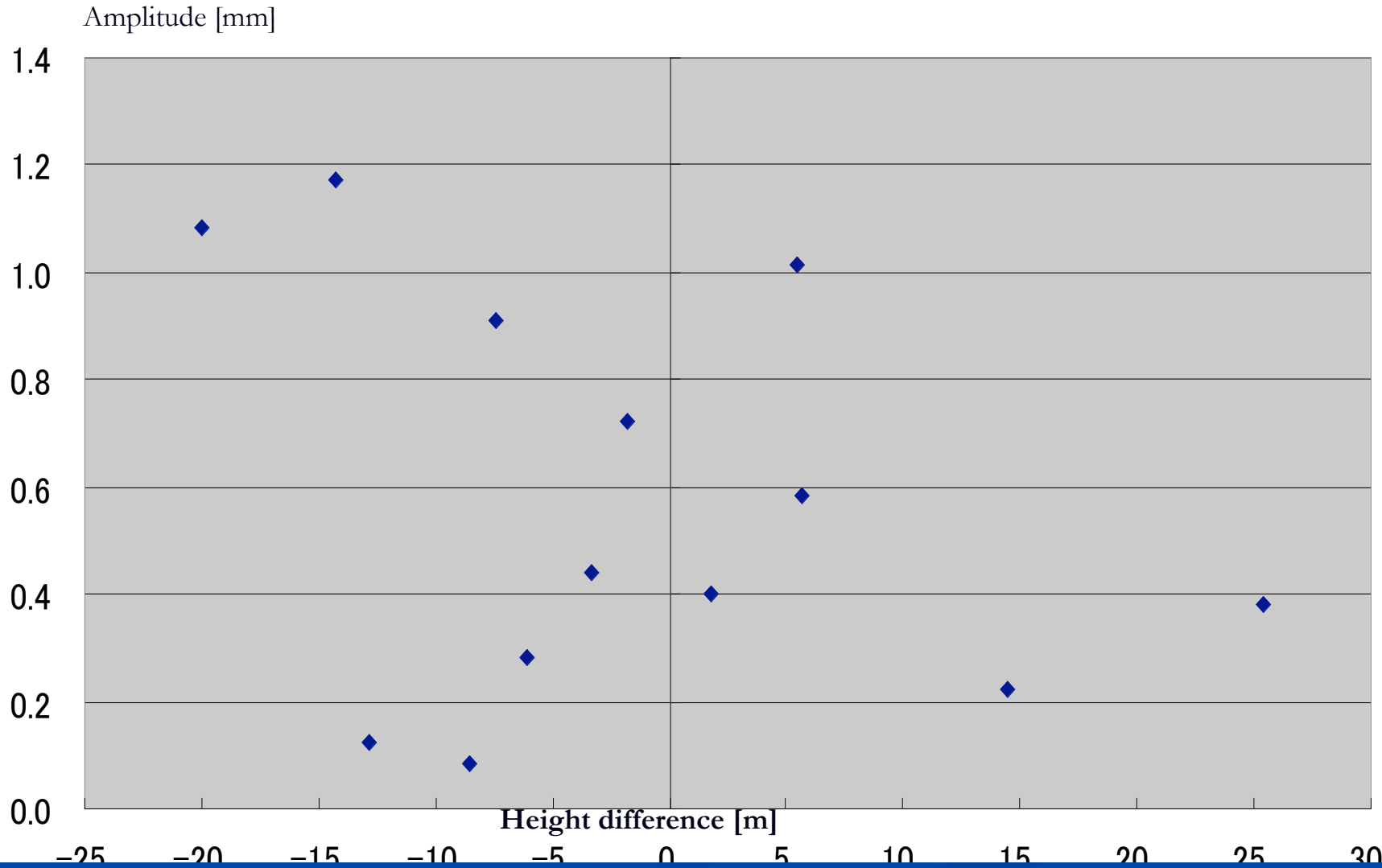
BM From	BM To	ΔH[m]	Trend [mm/yr]	Linear AIC	Amplitude	Max date	Linear +Annual AIC	note
140-1	2605	25.4235	-0.058	32.39	0.38	8/26	30.92	?
2605	2604	-19.9609	-0.855	71.26	1.10	8/2	43.50	O
2604	2603	-14.2647	-0.860	113.63	1.19	6/30	93.15	O
2603	*2602-1*	*-1.8033*	*-0.875*	*26.08*	*0.72*	*6/16*	*5.13*	*O*
2602-1	*2601*	*-7.3662*	*-0.447*	*51.68*	*0.91*	*6/24*	*26.48*	*O*
2601	*2600*	*-3.2811*	*-0.318*	*43.03*	*0.44*	*6/19*	*53.23*	*!*
2600	*2599*	*1.8104*	*-0.430*	*13.79*	*0.40*	*6/22*	*5.39*	*O*
2599	*2598*	*5.4423*	*-1.627*	*68.59*	*1.01*	*7/18*	*45.70*	*O*
2598	*2597*	*5.6849*	*0.420*	*139.78*	*0.59*	*4/29*	*64.37*	*O*
2597	*2596*	*-6.1149*	*-0.279*	*1.35*	*0.28*	*7/5*	*0.97*	*?*
2596	*2595*	*14.4502*	*-0.390*	*54.13*	*0.22*	*8/24*	*-12.48*	*O*
2595	2594	-12.7839	-0.270	10.73	0.13	4/9	14.12	!
2594	SF1354	-8.5169	0.246	-3.83	0.08	4/24	-0.15	!

Red numbers mean linear model is preferable, **yellow** numbers mean it is uncertain which model is preferable. *Italic means gap is estimated for linear model in that section*

Result of analysis

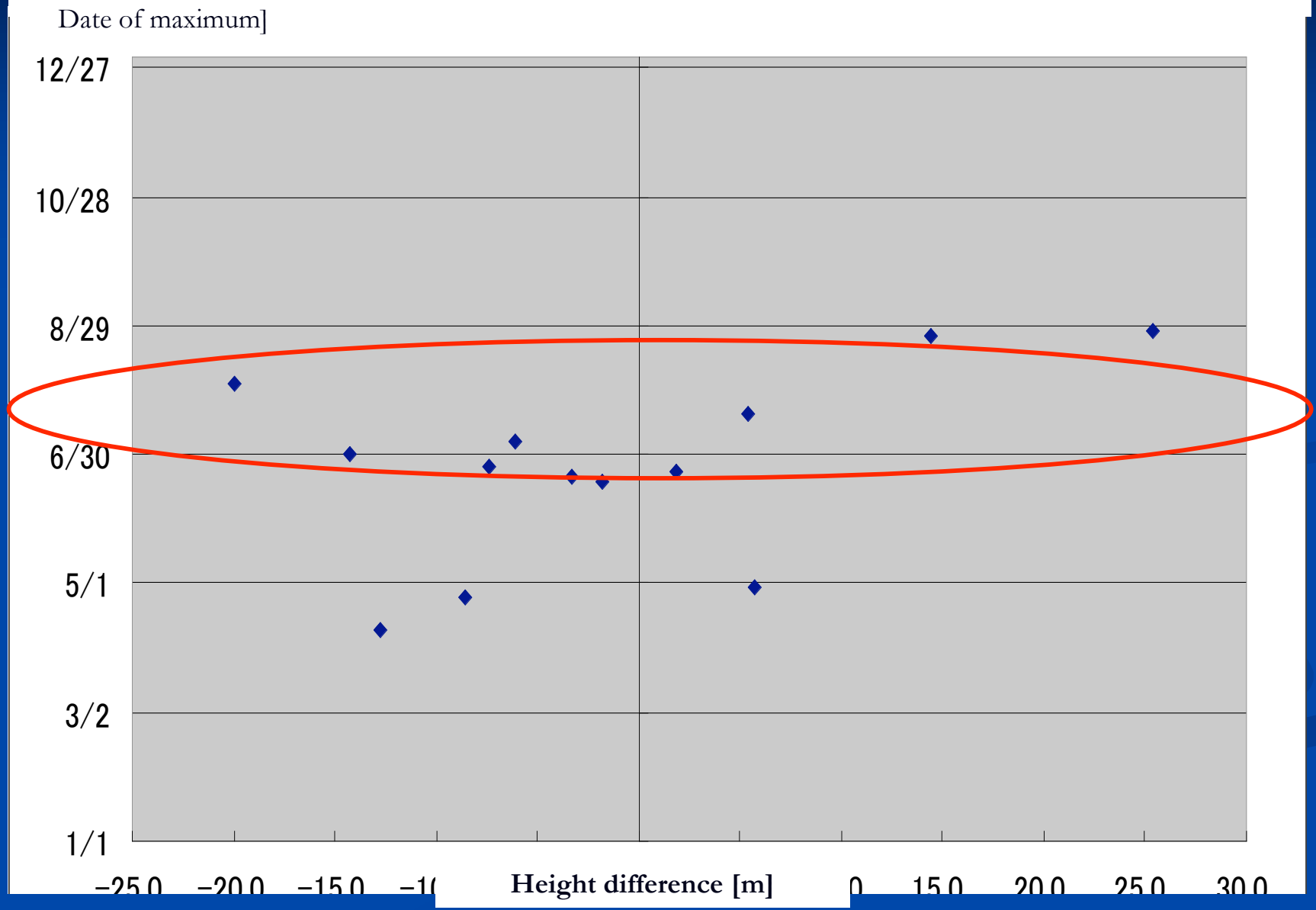
- Southern bench mark subside in winter in all sections where seasonal variation is seen
  - ➔ *There is no relationship between height difference and phase. (if refraction is origin of seasonal variation, the phase would be reverse in ascending sections and descending sections)*
- No clear correlation is seen between the height difference and amplitude of variation

Height difference and amplitude of seasonal variation



Height difference is measured from northern BM to southern BM

Height difference and phase of seasonal variation



Discussion

- Amplitude of seasonal variation should have positive correlation with absolute value of height difference, if it is

Then, what is the main cause of the seasonal variation?

- descending section and ascending section, if it is caused by atmospheric refraction, however, southern BMs subside relatively in winter in all sections where seasonal variation is seen.

↓

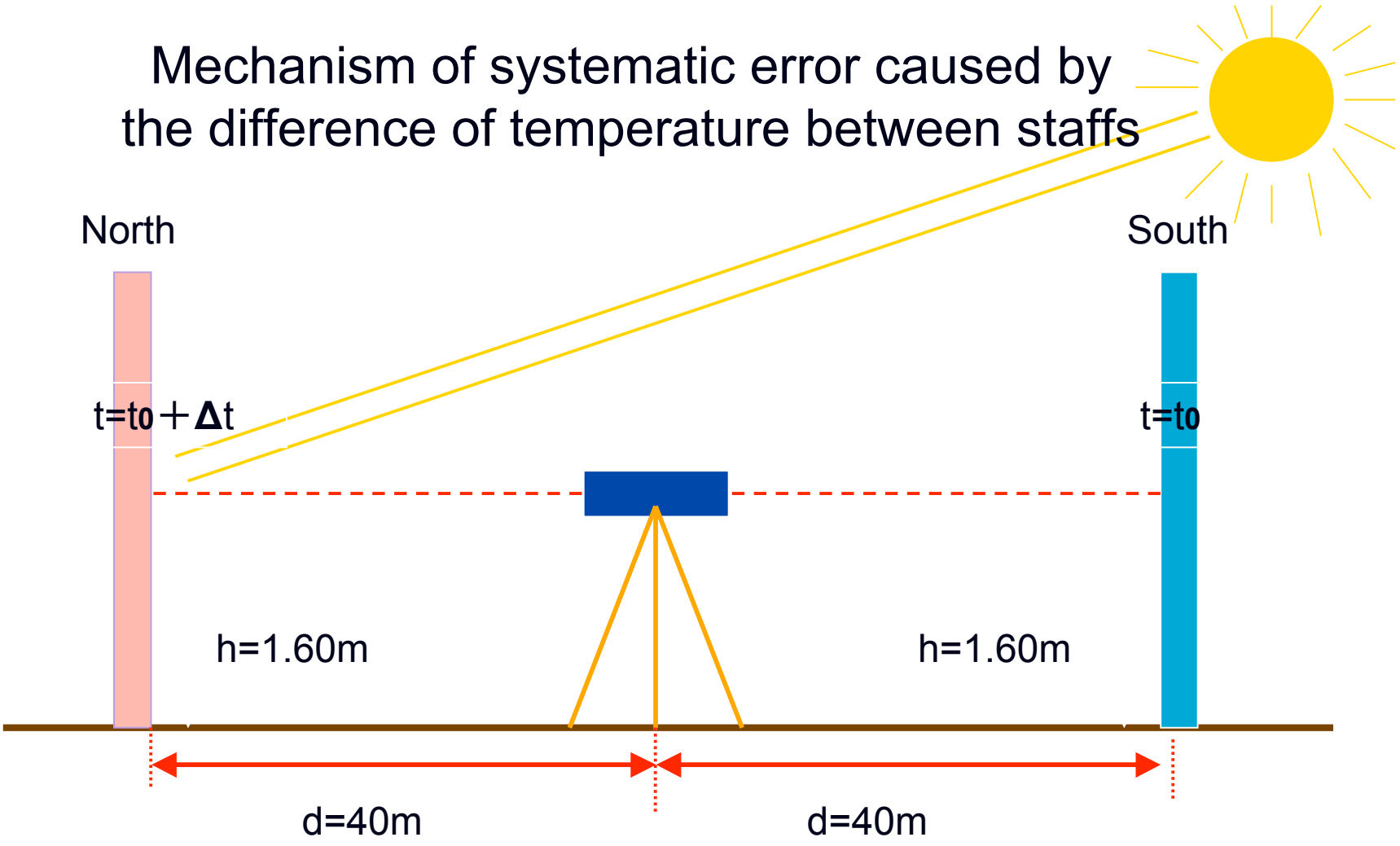
- *Atmospheric refraction would not be the main factor for seasonal variation*

4. Effect of thermal expansion of staff

- "Staff on the north side expands more heated by sunshine. As, difference of the temperature of two staffs is different in summer and winter, it causes the seasonal variation by the difference of systematic error "

- IF thermal expansion is the main reason of seasonal variation …
  - Amplitude of seasonal variation does not have positive any correlation with height difference
  - Seasonal variation would not be found in the section which goes east-west direction

Mechanism of systematic error caused by the difference of temperature between staffs



a : coefficient of extension for invar : 6x10E-7（1／℃）

Δt : difference of temperature between two staffs : ＋10℃

e : error of height difference measurement in one site

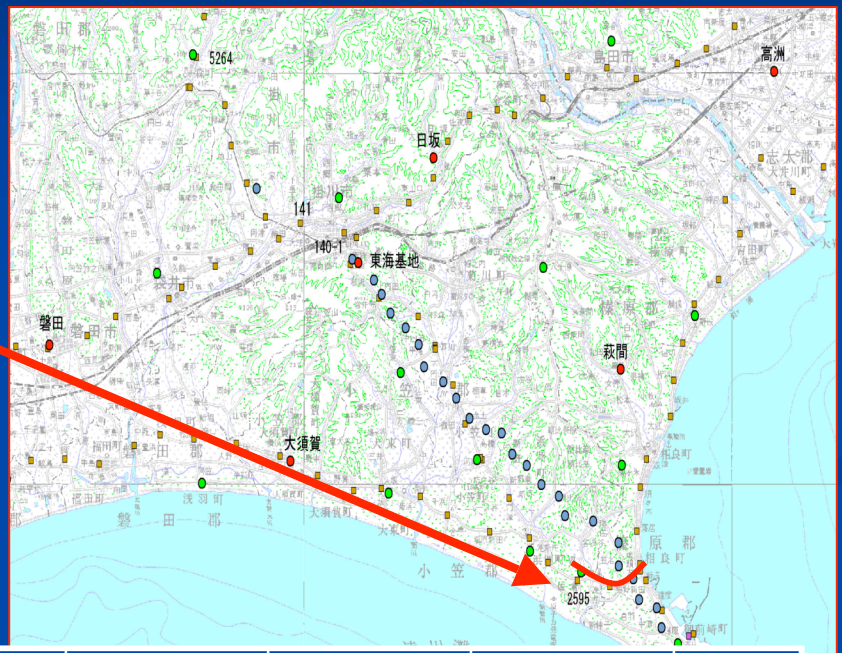
$$e = a * \Delta t * h = 6x10E\text{-}7 * 10 * 1600 = 0.0096mm$$

Survey route directing east-west

- No seasonal variation in the sections running to east from west.

  2595->2594, 2594->SF1354

- *This suggests direction of route relates the seasonal variation*



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2594	SF1354	−8.5169	0.246	−3.83	0.08	4/24	−0.15	!

Another fact

—suggesting the thermal expansion of staff—

- Amplitude of seasonal variation is smaller recently
- Regulation of survey procedure was changed on September 1999
  - Level used for survey:

    until September 1999, only tilting level was usable

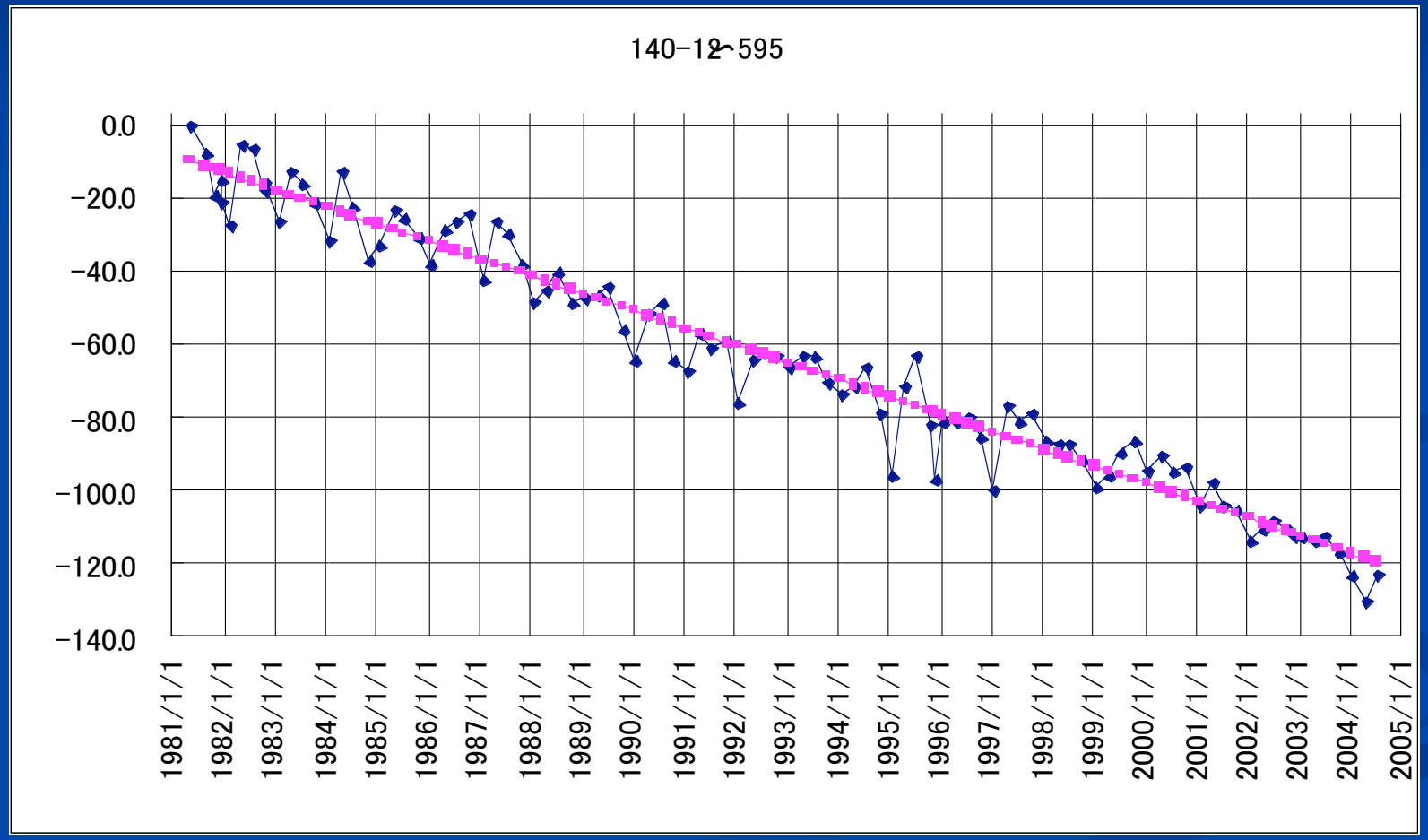
    after October 1999, auto level and digital level became usable
  - Observation procedure

    until September 1999, pointing twice and reading twice

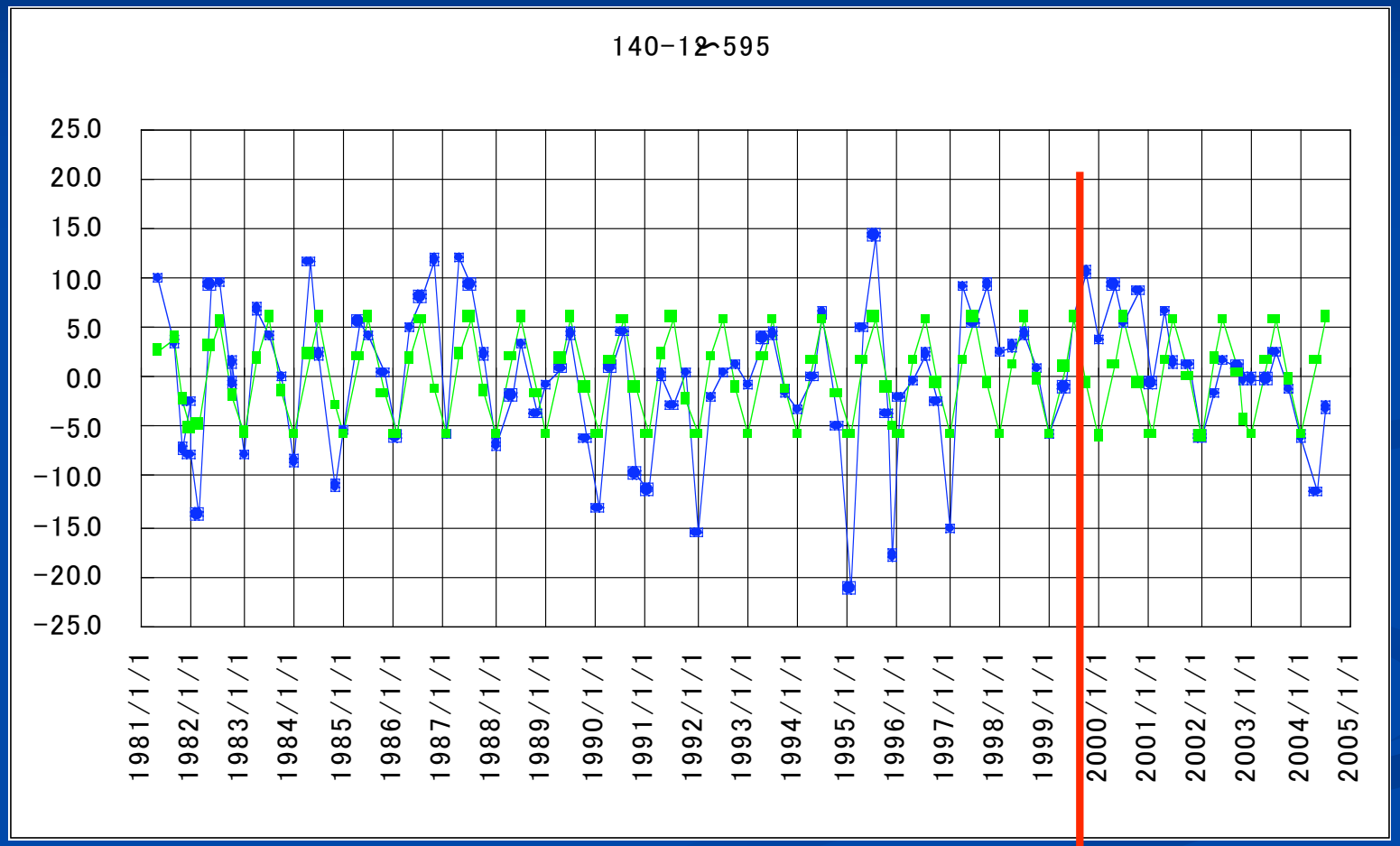
    after October 1999, pointing once and reading once

These changes allow observation time shorter

Notable feature of seasonal variation



Seasonal variation is smaller after 2000



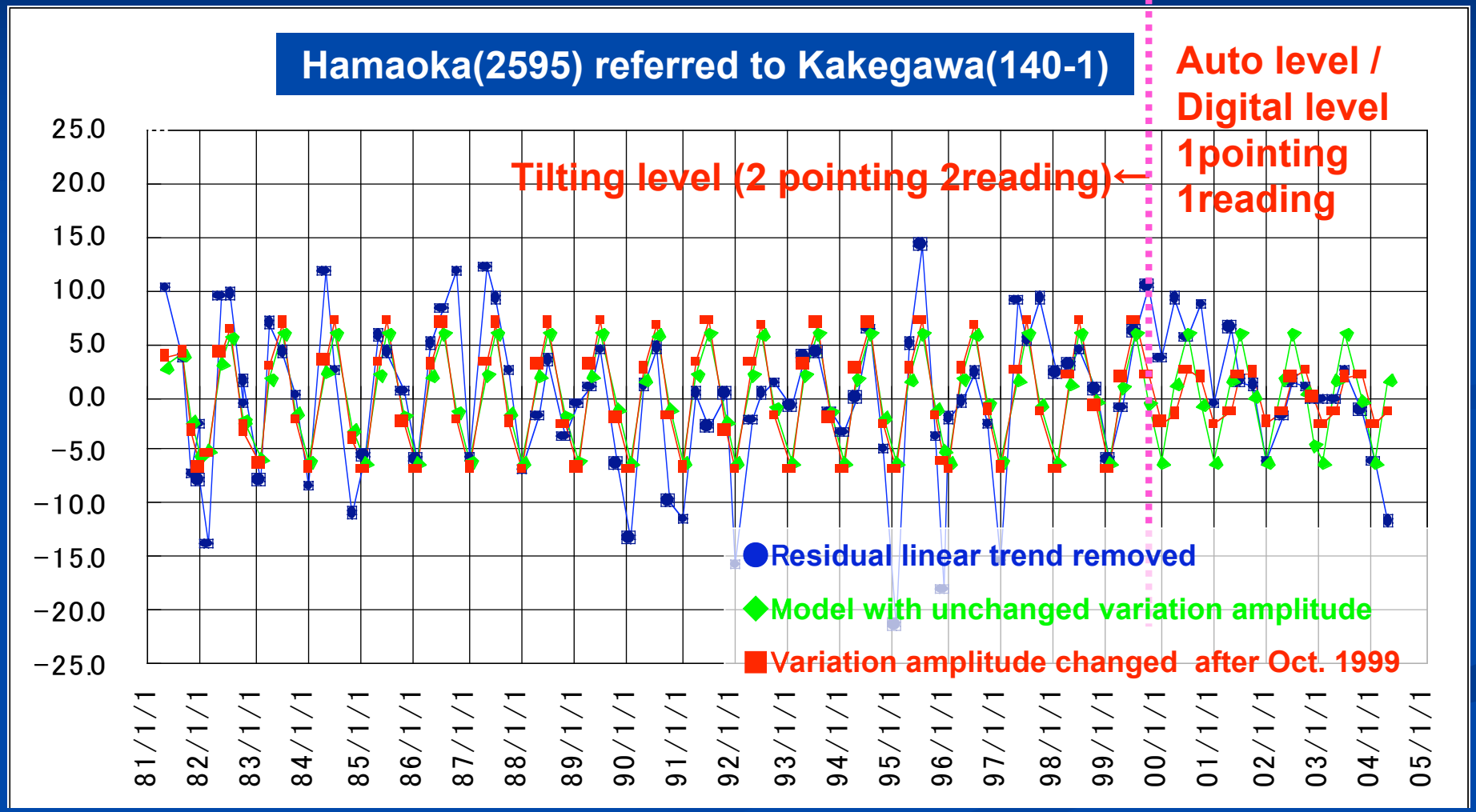
Observation time became shorter

Year	Section 2605–2604	Section 2599–2598
1981	0:06:53	0:06:21
1991	0:05:48	0:05:34
2001	0:02:47	0:02:52

- Observation time for one point was more than five minutes while only tilting level was usable
- Observation time became shorter than three minutes after auto level and digital level became usable

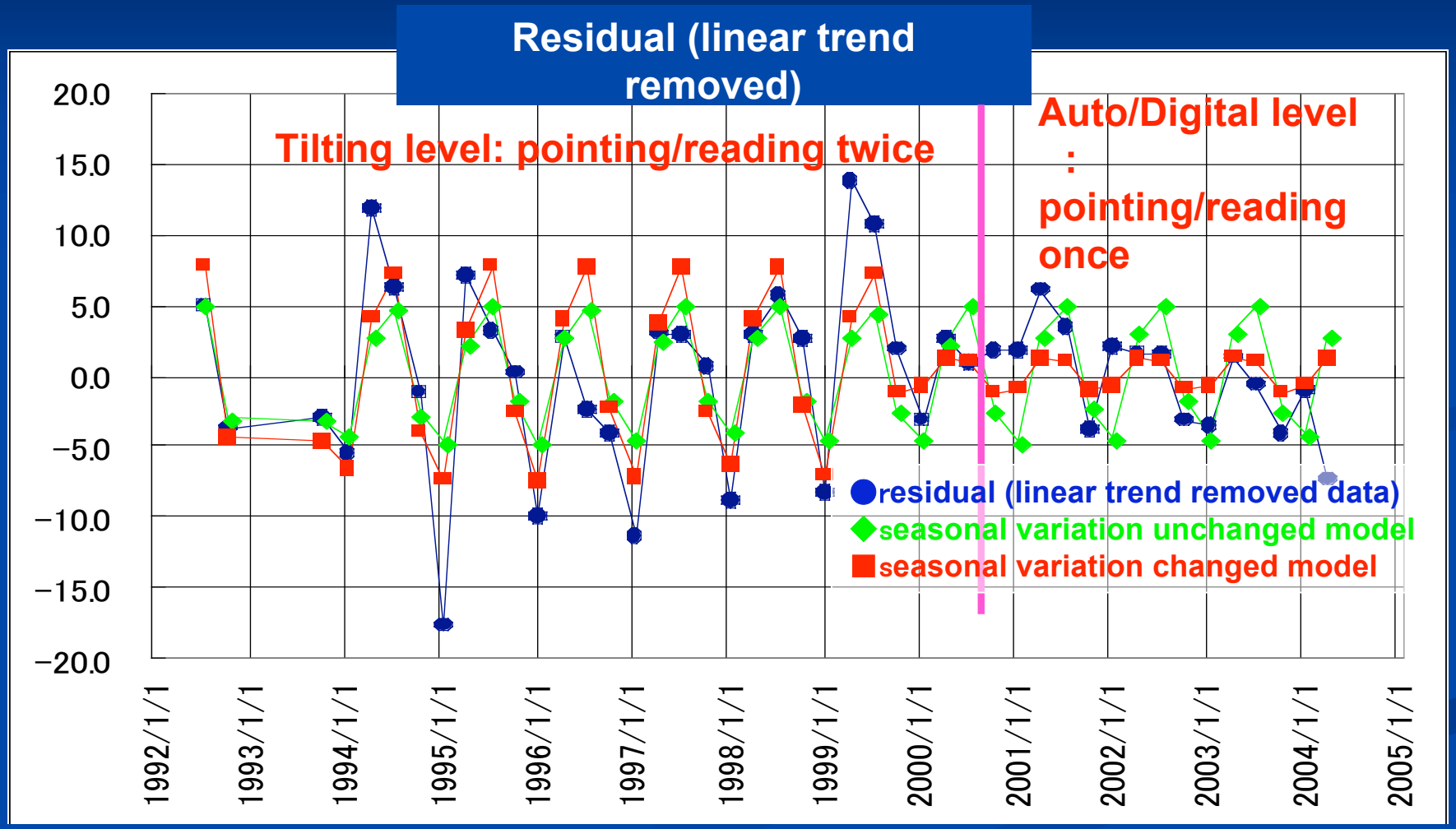
Effect of leveling survey procedure change

Residual (linear trend removed)

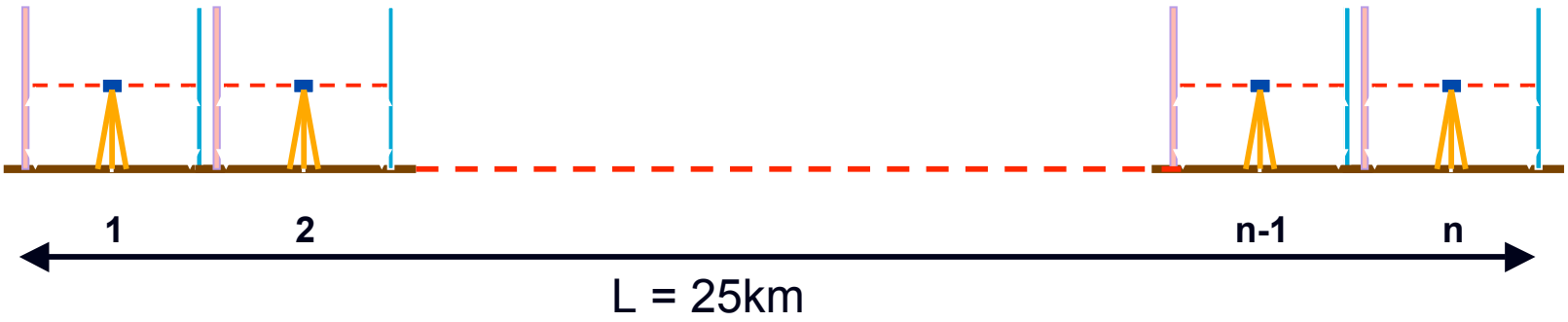


Effect of leveling survey procedure change

Mori(5268)～Kakegawa(140-1)



Estimation of the error



Suppose the leveling route is entirely flat (no height difference between starting BM and arriving BM)

The error is accumulative through the whole route and cannot been eliminated by forth and back observation

Total error in 25km leveling route is:

$$\Sigma e = n * e = 25{,}000 / (40 * 2) * 0.0096 = 3\text{mm}$$

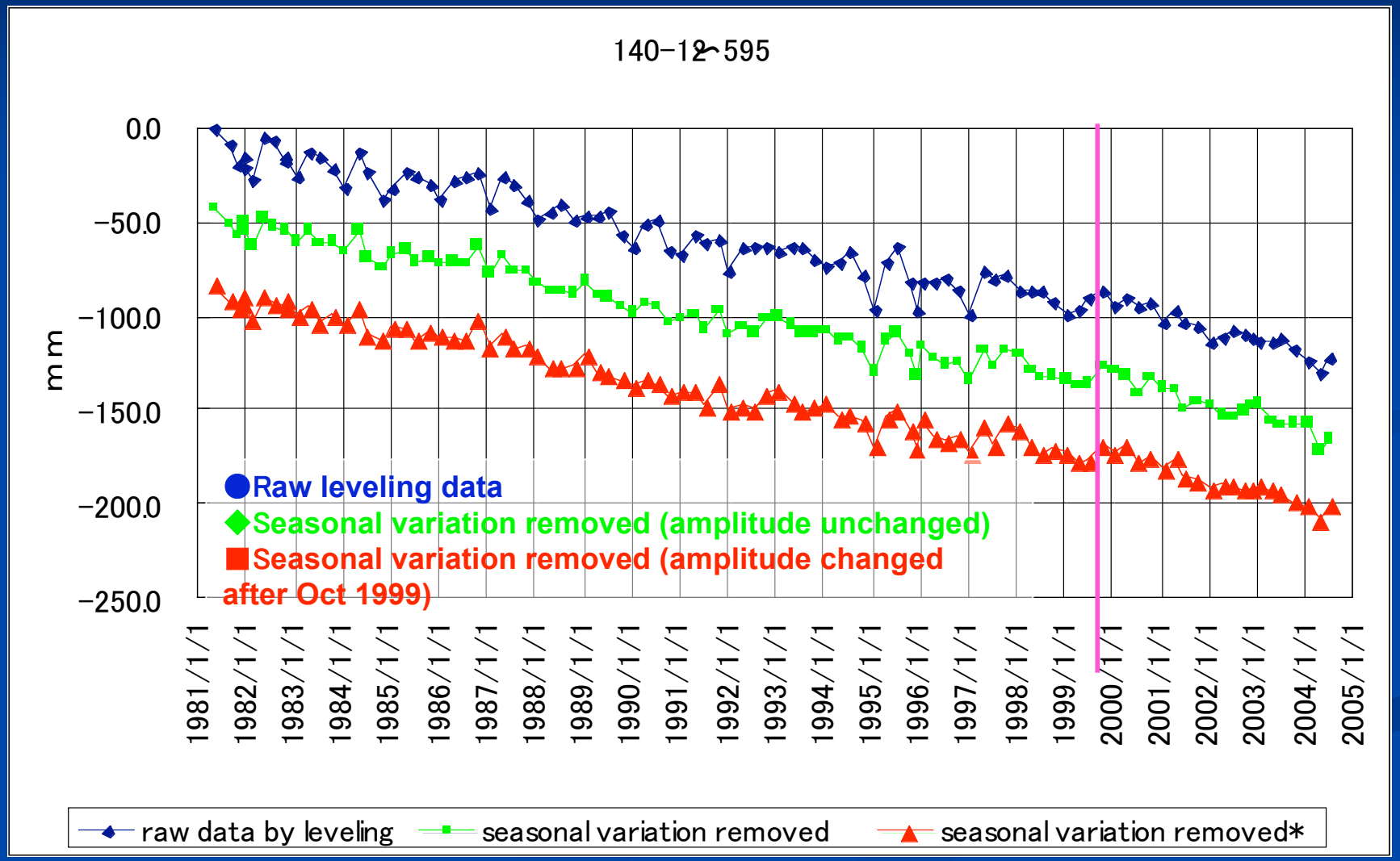
n≒400(In real route from Kakegawa to Hamaoka)

5. Conclusion

- The effect of atmospheric refraction is ***not essential*** for seasonal variation of leveling data along the route from Mori to Omaezaki via Kakegawa
- This seasonal variation is considered to be caused by ***the difference of temperature*** between northern staff and southern staff.
  - *Larger error that reading value of northern staff seems smaller than true value, which causes Hamaoka seems descending in winter.*

Removing seasonal variation

Kakegawa(140-1) to Hamaoka(2595)



Removing seasonal variation

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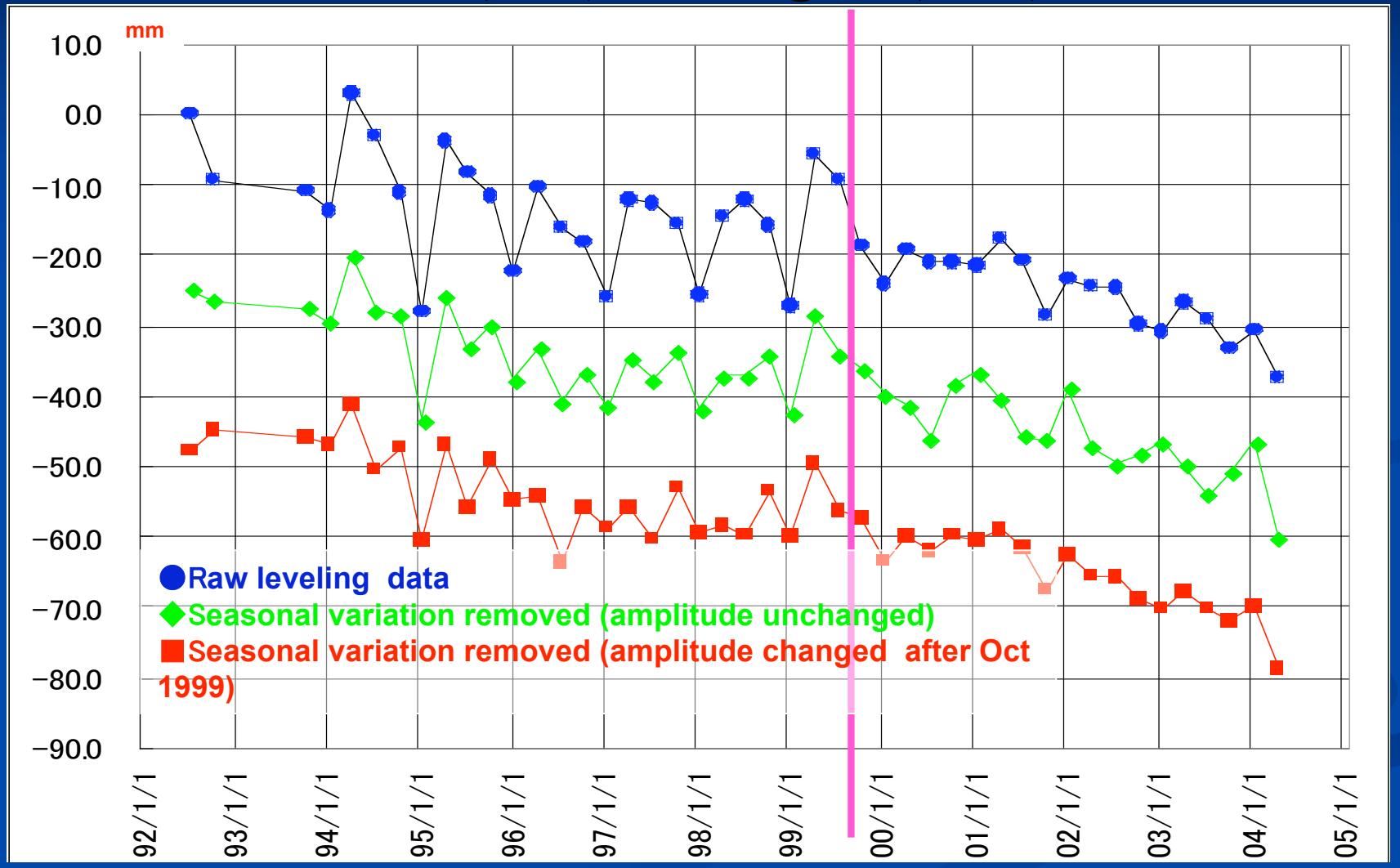

Next step

- Relationship between temperature and weather to the residual from linear fitting
- Measurement of temperature of leveling staff
  - attaching a thermometer on the invar and turning staff in several minutes cycle to face sunshine
- Compare the variations in different setting
  - higher line of sight
    - positive for refraction or negative for thermal extension
  - shorter distance from level to staff (increase observation site)
    - positive for refraction or negative for thermal extension

Thank you for your attention

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